

APPARATUS AND METHOD FOR INTEGRATED HYPOCHLORITE AND HYDROGEN FUEL PRODUCTION AND ELECTROCHEMICAL POWER GENERATION

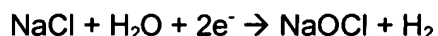
FIELD OF THE INVENTION

[0001] This invention is in the field of chemical production, more is more specifically
5 directed to an apparatus and method for producing two chemical products,
hypochlorite for use as a sanitizing solution and hydrogen as an energy source or an
industrial product.

BACKGROUND OF THE INVENTION

[0002] Chlorine in the form of hypochlorite, typically sodium hypochlorite, has been
10 used in the field of water treatment for over a century. Traditionally however it has
been chlorine gas that has been primarily used as a chlorine source for disinfecting
water. The transportation of chlorine gas has become a safety concern in recent
years. Sodium hypochlorite as an alternative source of chlorine is relatively safe to
transport but much more costly per unit of available chlorine as it is mostly water.

15 [0003] On-site sodium hypochlorite generation has been used as a relatively safe
and cost efficient way of providing chlorine for water treatment applications. Sodium
hypochlorite is made by reacting sodium chloride and water in the presence of a DC
current according to the following equation 1:



20 [0004] Previous systems of on-site sodium hypochlorite generation have vented
away the H_2 produced into the atmosphere.

[0005] Greenhouse gas (GHG) emissions have been identified as a contributor to
deleterious environmental effects. Fossil fuel consumption is a major source of GHG
emissions. As a result new technologies have emerged to provide energy without the
25 negative GHG by-products. One of these new technologies is hydrogen fuel cells or
Proton Exchange Membrane Fuel Cells (PEMFC).

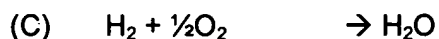
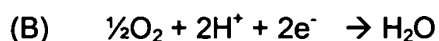
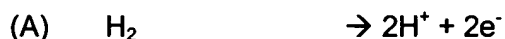
[0006] A hydrogen fuel cell is used to convert stored chemical energy into electrical
energy. Typically a fuel cell includes a cathode flow field plate, a gas diffusion layer, a

membrane electrode assembly, a second gas diffusion layer, and an anode flow field plate. Each flow field plate has an inlet and an outlet connected by open-faced channels that provide a means of distributing reactant gases to the membrane electrode assembly. The membrane electrode assembly typically includes a solid electrolyte sandwiched between a cathode catalyst and an anode catalyst.

[0007] Operation of the fuel cell involves the input, flow and output of an anode reactant gas and a cathode reactant gas on their respective flow field plates. As these gases pass through the channels of their respective flow field plates they are forced to pass through their respective gas diffusion layers. In passing through these layers the gases will come into contact with their respective catalyst layers.

[0008] The anode catalyst helps the anode reactant gas separate into reaction intermediates. Reaction intermediates include ions and electrons. Only the ions may pass through the solid electrolyte of the membrane electrode assembly to come into contact with the catalyst layer on the cathode side of the fuel cell. The cathode catalyst interacts with the cathode reactant gas and the reaction intermediates converting the cathode reactant gas into the chemical product of the fuel cell reaction. The chemical product passes through the gas diffusion layer back to the cathode flow field plate and is transferred along the channels of the plate to its outlet.

[0009] The solid electrolyte is a barrier to the flow of the electrons created as reaction intermediates at the anode catalyst. The electrons can flow from the anode side to the cathode side of the membrane electrode assembly if the two sides are electrically connected using an external load between the anode flow field plate and the cathode flow field plate. The anode reaction in this case is an oxidation reaction as electrons are released at the anode catalyst. Conversely the cathode reaction is a reduction reaction where electrons are consumed. The specific anode (A), cathode (B), and overall fuel cell reaction (C) are represented as:



[0010] To increase the electrical output, a plurality of fuel cells can be arranged in series to form a fuel cell stack. In a stack arrangement one side of a flow field plate functions as the anode flow field plate for one fuel cell while the other side of the flow field plate functions as the cathode flow field plate for another fuel cell.

5 [0011] Referring now to FIG. 1 illustrating a hypochlorite production system **100** disclosed in US Patent No. 6,468,412. The system includes an electrolyzer **106** that requires a source of brine **102** which may be either a synthetic source such as a salt saturator **102** or a natural source such as sea water. The brine is metered by a pump **104** into the electrolyzer **106** containing electrolytic cell **105** where electrolysis
10 occurs. The electrolytic cell **105** contains cathodes and anodes. A separate softened water supply may be provided to the electrolyzer to optimize the brine concentration within. The resultant hypochlorite solution is transferred past product outlet **109** and travels through solution line **110** to storage tank **111**.

[0012] Hydrogen gas, produced in addition to hypochlorite in the electrolyzer **106**,
15 passes with the hypochlorite solution through solution line **110** into the storage tank **111** where it separates from the liquid product. In other embodiments some separation may occur in the electrolyzer **106** itself with a gas vent connected to the top of the electrolyzer **106** allowing for the flow of hydrogen gas directly into the storage tank. The storage tank is provided with a vent **112** that allows the hydrogen
20 to exit the system into the atmosphere. An air blower **116** may also be connected to the storage tank to provide a forced flow of air to purge the hydrogen in the storage tank into atmosphere. In further embodiments a fan may be attached to individual electrolyzers **106**. Hydrogen is thus not collected for future utility.

[0013] UK Patent Application No. 2,068,016 discloses an electrolyzer with
25 electrolytic cell assembly **200** as shown in Fig. 2. The electrolyzer casing **210** is typically cylindrical and is sealed on its end flanges with removable covers **201**, and gaskets **205**. Electrically non-conductive partitions **209** are spaced evenly along the length of tie rod **214**. Spacer **213** is fitted over the tie rod **214** and abuts the partitions **209**. Titanium electrode support blocks **211** are secured on both sides of the
30 partitions **209**. Conductor studs **204** and **215** are connected on opposite flanges of

the electrolyzer. Brine inlet and product outlet are not shown. Product or brine passageway **212** exists between the circumference of the partition **209** and the electrolyzer casing.

5 [0014] The electrolytic cell assembly encompasses anode plates **206** and cathode plates **207**. Both anode and cathode plates **206 207** are aligned in parallel and spaced alternately in fixed increments. Clamping washers **202** are inserted to between successive anode and cathode plates. Electrode plates and washers are assembled over rods that are not shown and are secured using clamping nuts **208**.

10 [0015] Referring now to FIG. 3 illustrating further parts of the electrolyzer **300** of Fig. 2. This particular schematic shows a hydrogen vent port **301** where evolved hydrogen from the gas zone **302** is removed and product discharge connection **308** where hypochlorite from electrolyte zone **303** are both under atmospheric pressure with the overflow trap **307** regulating the level of product in the electrolyzer to the approximate level in the discharge connection. The gas bleed orifice **309** provides an
15 additional route with which to remove evolved hydrogen. Hydrogen is not shown to be collected.

[0016] Referring now to FIG. 4, a prior art proton exchange membrane fuel cell **400** is reviewed in US Patent No. 6,569,298. The proton exchange membrane fuel cell is comprised of a centrally located membrane electrode assembly **401**, which includes
20 an anode electrode layer **404**, a cathode electrode layer **408**, an electrocatalyst layer **405** between the anode electrode and the membrane electrode assembly, and an electrocatalyst layer **407** between the cathode electrode **408** and the membrane electrode assembly **401**.

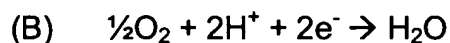
[0017] The electrocatalyst layers **405** and **407** promote the desired electrochemical
25 reaction. The polymer membrane electrode or electrolyte **406** readily permits the flow of ions between the anode electrode layer **404** and the cathode electrode layer **408** but is relatively impermeable to gases and electrons.

[0018] During the operation of the proton exchange membrane fuel cell **400**, hydrogen flows through channels **403** that are part of the anode flow field plate **402**.
30 The hydrogen is forced to travel through anode electrode layer **404** leading to contact

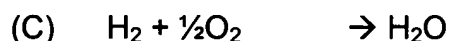
with electrocatalyst layer **405**. The contact of hydrogen with electrocatalyst layer **405** yields electrons and hydrogen ions in an oxidation reaction. These hydrogen ions will then migrate through the electrolyte **406**. The reaction at electrocatalyst layer **405** is given by:



[0019] Simultaneously, oxygen flowing through channels **409** that are part of the cathode flow field plate **410** is forced to travel through cathode electrode layer **408**. In the cathode electrode layer the oxygen will combine with any hydrogen ions that have migrated through the electrolyte **406** and electrons from the cathode electrode
10 layer **408** to form water. This electrochemical reaction is given by:



[0020] The overall electrochemical reaction for the proton exchange membrane fuel cell **400** is therefore:



15 [0021] A stream of electrons **412** travels from the anode flow field plate **402** through an electrical load **411** to the cathode flow field plate **410** to provide electrons for the reaction occurring at the cathode electrocatalyst layer **407**.

[0022] FIG. 5 shows a further prior art proton exchange membrane fuel cell stack of the invention reviewed in US Patent No. 6,569,298 and utilizing an internal module
20 for humidification of the reactants **500**. The assembly **500** includes a proton exchange membrane fuel cell stack **504**, an internal module for humidification of the reactants **505**, an electrochemically active region **506**, a water softening or deionization apparatus **501**, a softened water reservoir **502**, and a heat exchanger **508**. In the assembly **500** the softened water can be used for both conditioning of the
25 reactant gases and heat transfer away from the fuel cell stack **204**. To accommodate both functions water is simultaneously injected through the humidification module **505** and through cooling elements **507** positioned along the length of the electrochemically active module **506**.

[0023] A hydrogen fuel stream is delivered to fuel inlet port **509** while a stream of compressed oxidizer is likewise delivered to oxidizer inlet port **510**. The reactants are both distributed to the electrochemically active region **506**. Excess hydrogen and oxidizer exit the proton exchange membrane fuel cell stack **504** respectively through fuel outlet port **511** and oxidizer outlet port **512**. Excess fuel may be re-circulated back into the fuel stream using an appropriate purification and pumping system (not shown).

[0024] Proper temperature management of the proton exchange membrane fuel cell stack **504** is critical maintaining the functionality of the unit. Softened water is injected through coolant inlet port **513** and is circulated through the humidification module **505**, and the cooling elements **507** within the electrochemically active module **506**. The water and adsorbed heat then exits through coolant outlet port **514** and is received by the heat exchanger **508** where the water is cooled to approximately its original temperature.

[0025] The potential difference produced by the fuel cell stack **504** occurs across positive terminal **515** and negative terminal **516**. A DC current may be forced through a power handling module **517** where it could be used directly or subsequently it can be converted into AC current by power-conditioning module **518**.

[0026] FIG. 6 is a schematic view of a prior art proton exchange membrane electrolysis device and hydrogen storage system **600** reviewed in US Patent No. 6,569,298. The system is generally comprised of an electrolysis stack **601** sandwiched between a cathode plate **606** and an anode plate **605**. A hydrogen manifold **616** is positioned at the cathode plate **606** and an oxygen manifold **617** is positioned at the anode plate **605**. The cathode plate **606** and the anode plate **605** are coupled to a DC power supply **604**. The electrolysis stack **601** is further coupled to a water deionization module **603** that delivers treated water to the electrolysis stack **601**. Treated water is also circulated through the electrolysis stack **601** by a recirculation pump **612** for cooling or other purposes.

[0027] During operation of the electrolysis device and hydrogen storage system **600**, externally supplied water from a municipal source is fed through the water

deionization module 603. The purified water stream 615 flows to a water storage container 609 and is subsequently fed into the electrolysis device. Water fed into the electrolysis stack 601 is evolved into hydrogen and oxygen at the cathode and anode respectively. A two-phase mixture of hydrogen and water is collected at the hydrogen manifold 616 while a two-phase mixture of oxygen and water is collected at the oxygen manifold 617. The two-phase mixture of hydrogen and water flows through line 618 where check valve 620 prevents the back-flow of the mixture into the electrolysis stack 601. A phase separator 614 divides the evolved hydrogen gas from the remaining water where the water portion is returned to the water storage container 609. Another phase separator 613 divides the evolved oxygen gas from the remaining water having entered the separator through line 619 containing check valve 621 to prevent back-flow. The water portion of the oxygen-water separation is also returned to water storage container 609.

[0028] The produced hydrogen gas is purified further following the phase separator 614 by condenser 611. The purified hydrogen is then passed through a hydrogen outlet port 607, through check valve 622 to a mechanical compression system 623. The product hydrogen is then accumulated in fuel storage system 624. In this description the storage system 624 is assumed to comprise a plurality of pressure vessels 625 with a safety relief valve 626, a control valve 627, and a dispensing regulator 628 fluidly coupled to the vessels 625. Burst discs 629 have been illustrated as a safety precaution against over pressurizing the pressure vessels 625. The product oxygen flows from the phase separator 613 into a condenser 610 to remove residual water and is then routed through oxygen outlet port 608 to leak valve 630.

SUMMARY OF THE INVENTION

[0029] One object of this invention aims to collect the H₂ in during hypochlorite generation for use in a power generating capacity.

[0030] The objective of the present invention is to provide an integrated system for the production, separation and collection of both hypochlorite and hydrogen. In accordance with a preferred embodiment of the invention, an apparatus for producing hypochlorite and generating electrochemical power is provided that comprises: an

electrolyzer for generating hypochlorite and hydrogen in fluid communication with a source of brine and in electrical communication with a source of electrical energy, the electrolyzer having an electrolyzer outlet for spent brine solution, generated hypochlorite and hydrogen; a separator for separating spent brine and generated
5 hydrogen and hypochlorite in fluid communication with the electrolyzer outlet; a fuel cell for generating electrochemical power in input fluid communication with a source of oxidizer and output electrical communication with a power handling module; a hydrogen conduit for controllably transporting hydrogen separated by the separator to the fuel cell and a hydrogen storage system; a hypochlorite conduit for removing
10 hypochlorite separated by the separator from the separator; and a brine conduit for transporting brine separated by the separator.

[0031] Another preferred embodiment is directed to a method for producing hypochlorite and generating electrochemical power comprising the steps of: producing hypochlorite and hydrogen in an electrolyzer from brine received from a
15 source of brine; separating in a separator spent brine and generated hydrogen and hypochlorite received from the electrolyzer; generating electrochemical power in a fuel cell using generated hydrogen and an oxidizer received from a source of oxidizer; and directing generated hypochlorite from the separator to a hypochlorite storage.

[0032] In accordance with another aspect of the invention, the apparatus operates in a hypochlorite and hydrogen production mode, with a water softener receiving water from a water source, transferring softened water to salt saturator, transferring brine solution to an electrolyzer or plurality of electrolyzers containing at least one electrolytic cell where hypochlorite and hydrogen are evolved. Separation can occur
25 during and after the production mode both in the electrolyzers and in the final hypochlorite storage tank. Collection of the hypochlorite can occur in a closed top tank where further hydrogen can be separated and then stored usually in pressurized containers. Hypochlorite can be utilized in a water disinfection capacity while the hydrogen can be accessed in a power generation capacity using a variety of control
30 methods. Alternatively the hydrogen can be used in a variety of industrial processes.

[0033] The system of the present invention will produce two economic products: hypochlorite for use as a sanitizing solution and hydrogen as an energy source. Specifically the invention will allow for the establishment of a basic hydrogen fuel infrastructure in a cost-effective manner in the absence of current demand. An
5 established hydrogen fuel infrastructure may expedite the production and sale of hydrogen fueled vehicles and power generators.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Preferred, non-limiting embodiments of the present invention will be described by way of example with reference to the accompanying drawings, in which:

10 [0035] FIG. 1 is a schematic diagram of a prior art hypochlorite production system.

[0036] FIG. 2 is a sectional top view of a prior art electrolyzer with contained electrolytic cell assembly.

[0037] FIG. 3 is a schematic diagram of a prior art electrolyzer.

[0038] FIG. 4 is a sectional view of a prior art proton exchange membrane fuel cell.

15 [0039] FIG. 5 is a schematic sectional view of a prior art proton exchange membrane fuel cell stack utilizing an internal module for humidification of the reactants.

[0040] FIG. 6 is a schematic view of a prior art electrolysis device and hydrogen storage system.

20 [0041] FIG. 7 is a schematic diagram of an apparatus for the production, separation, and storage of hypochlorite and hydrogen according to a preferred embodiment of the invention.

[0042] FIG. 8 is a schematic diagram of an apparatus for the production, separation, and storage of hypochlorite and hydrogen integrating a fuel cell according
25 to a preferred embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0043] The present invention is generally directed to an integrated system for generating both a disinfecting agent and power. Many of the specific details of certain embodiments of the invention are set forth in the following description and in FIGS. 7 and 8 to provide a thorough understanding of such embodiments. One who is skilled in the art will understand, however, that the present invention may have additional embodiments, or that the present invention may be practiced without several of the details described in the following description.

[0044] FIG. 7 is a schematic diagram of an apparatus for the production, separation, and storage of hypochlorite and hydrogen **700** according to a preferred embodiment of the invention. The apparatus **700** is comprised of a brine electrolyzer **703**, a hypochlorite storage and hydrogen separation vessel **704**, and a hydrogen storage system **715**. The internal details and operation of the electrolyzer **703**, the hypochlorite storage and hydrogen separation vessel **704**, and the hydrogen storage system **715** are well known to a person skilled in the relevant art.

[0045] Operation of the apparatus **700** may require water to be delivered to a water deionizer **701**. The source of the water may be either potable or non-potable. The flow rate of the water may be dictated by various factors and may include but not be limited to the level of hypochlorite in the storage vessel **703** or the dosing rate of the metering pump **714**. Once the water has been softened to a sufficient level it is delivered to salt saturator **702** where salt is added to the water to create a brine solution that is input into the electrolyzer **703**. Within the electrolyzer **703** a direct current is applied to cause the brine solution to evolve into hypochlorite and hydrogen in accordance with Equation 1 above. Electrical connections and power conversion devices are not shown but implied.

[0046] In the electrolysis process, hypochlorite and hydrogen are evolved and flow as a two-phase mixture out of the electrolyzer **703** into the hypochlorite storage vessel **704** where phase separation into liquid hypochlorite solution **705** and gaseous hydrogen **706** occurs. Some separation may occur within the electrolyzer **703** itself and any separated hydrogen may be vented out of individual electrolyzers via a vent

line **719** directly into the hypochlorite storage vessel **704** to increase the efficiency of any downstream electrolyzers. Additionally, dedicated phase separators and condensers may be employed to purify the hydrogen but are not shown on the diagram. A gas outlet valve **707** allows for evolved hydrogen to be vented to atmosphere in the case of a failure of the hydrogen storage system or the hydrogen fuel cell. A fan that is not shown may be used to purge the system of hydrogen under any alarm conditions in conjunction with the opening of the outlet valve **707**. Check valve **708** prevents the backflow of hydrogen back into the storage vessel **704**.

[0047] When the hydrogen gas has been sufficiently purified it may pass through vacuum regulator **716** to compressor **709**. The compressor **706** transfers the hydrogen to storage or directly into a proton exchange membrane fuel cell. Pressure sensor **718** monitors the pressure in the storage system and may be used in controlling the operation of the system. Control valve **710** is used to dictate the direction of gas flow either into the hydrogen storage system **715** or through pressure regulator **717** and then to a proton exchange membrane fuel cell (not shown). A plurality of vessels **711** may be utilized in storing the hydrogen. Safety relief valve **712** is attached at the manifold of the pressure vessels to expulse any excess pressure and prevent vessel rupture. Burst discs not shown may also be included on the pressure vessels. The flow of hydrogen from the pressure vessels **712** to a proton exchange membrane fuel cell may be controlled by a pressure regulator **713**.

[0048] FIG. 8 is a schematic diagram of an apparatus **800** for the production, separation, and storage of hypochlorite and hydrogen integrating fuel cell **800** according to a second preferred embodiment of the invention. The apparatus **800** is comprised of a brine electrolyzer or plurality of electrolyzers **804**, a hypochlorite storage and hydrogen separation vessel **807**, a hydrogen storage system **816**, a proton exchange membrane fuel cell **837**. The internal details and operation of electrolyzer **804**, hypochlorite storage and hydrogen separation vessel **807**, hydrogen storage system **816**, and proton exchange membrane fuel cell **837** are well known to a person skilled in the relevant art..

[0049] Operation of the apparatus **800** requires a source of water to be delivered to a water deionizer **801** as with the other preferred embodiment discussed. The source of the water may be either potable or non-potable. Softened water from the water deionizer **801** is supplied to salt saturator **803** to create a brine solution. Softened water may similarly distributed to proton exchange membrane fuel cell **837** through valve **802** and supply line **829** to cool the fuel cell **837** and also to electrolyzer **804** through water line **834** to dilute the brine concentration in the electrolyzer **804** if necessary. Brine created in the salt saturator **803** is metered into electrolyzer **804** where a direct current is applied to the solution in order to evolve hypochlorite and hydrogen. A series of electrolyzers **804** is shown in Fig. 8 with each having an optional hydrogen gas port **839** to remove hydrogen that has separated from the solution in each cell therefore by-passing any downstream electrolyzers **804**. The separated hydrogen flows through hydrogen gas line **806** into hypochlorite storage and hydrogen separation vessel **807**. The solution mixture of hypochlorite, entrained hydrogen, and unspent brine exits the final electrolyzer **804** in the series and flows through solution line **805** to the hypochlorite storage and hydrogen separation vessel **807**.

[0050] Within the hypochlorite storage and hydrogen separation vessel **807**, two distinct phases are present: the liquid hypochlorite phase **808** and the gaseous hydrogen phase **809**. The liquid hypochlorite phase **808** is metered as a disinfecting agent into a water system by metering pump **833** but could also be transferred to another storage device to be transported to an off-site (disinfection) system. A gas outlet valve **810** is attached to the top of the vessel **807** allowing for evolved hydrogen to be vented to atmosphere in the event of a failure of the hydrogen storage system **816** or the fuel cell **837**. A fan (not shown) may be connected to the vessel **807** to purge any evolved hydrogen into the atmosphere through gas outlet valve **810** during an alarm condition.

[0051] Successive hydrogen purification mechanisms (not shown) may be used in addition to the primary separation vessel **807**. When the hydrogen gas has been sufficiently purified it will pass through vacuum regulator **812** to compressor **813**. An optional check valve **811** will prevent the backflow of hydrogen. The compressor **813**

provides the necessary pressure to store the hydrogen as compressed gas or feed the gas directly to the fuel cell **837**. Pressure sensor **814** monitors the pressure in the hydrogen storage system **816** and may be used in the control scheme of the entire system. Control valve **815** is used to direct the flow of hydrogen to either the hydrogen storage system **816** or the fuel cell **837** or proportionally to both. A plurality of pressure vessels **817** may be employed based on the demands of the system **800**. A safety relief valve **838** is attached at the manifold of the pressure vessels **817** to expulse any excess pressure and prevent a vessel **817** rupture. Pressure regulator **818** may be used to control the flow of hydrogen from the pressure vessels **817** to the fuel cell **837**. Likewise pressure regulator **820** may be used to control the flow of hydrogen from the compressor **813** to the fuel cell **837**.

[0052] Isolation control valves **819** and **835** allow for the selection of either the stored or direct source of hydrogen for the fuel cell **837**. Hydrogen fuel flows into the humidification module **822** of the fuel cell **837** through hydrogen inlet **821**. The chosen oxidizer flows into the humidification module **822** of the fuel cell **837** through oxidizer inlet **831**. Softened water from deionizer **801** is transferred to the fuel cell **837** for humidification and cooling through water supply line **829**. The water is removed from the fuel cell **837** via water waste line **830**. Humidified hydrogen and oxidizer are transferred into the electrochemically active module **823** where the electrochemical reaction creates a potential difference between positive electrode **824** and negative electrode **825**. The potential difference across the electrodes **824** **825** produces a DC which is accepted by power handling module **827** where it could be applied directly to a load (not shown) or converted to AC current by power-conditioning module **828** and then applied to a load.

[0053] Unused hydrogen from the electrochemical reaction may be re-circulated back through the system **800** via hydrogen return line **826** or it may be exhausted to atmosphere through a gas outlet valve that is not shown. Check valve **836** prevents the backflow of hydrogen. Oxidizer that is not reacted is exhausted to atmosphere through the oxidizer outlet **832**.

[0054] The above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Specific embodiments and examples of the invention are described in the foregoing for illustrative purposes, however, this should not exclude various modifications within
5 the scope of the invention as those skilled in the art will recognize.